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TRANSISTOR

STEP STRESS TESTING PROGRAM

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FINAL REPORT
FOR

JANTX 2N2605

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Prepared
For

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FOREWORD

This report is a summary of the work performed on NASA Contract NAS8-31944. The investigation was conducted for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama. The Contracting Officer's Technical Representative was Mr. F. Villella.

The short-term objective of this preliminary study of transistors, diodes, and FETS is to evaluate the reliability of these discrete devices, from different manufacturers, when subjected to power and temperature step stress tests.

The long-term objective is to gain more knowledge of accelerated stress testing for use in future testing of discrete devices, as well as to determine which type of stress should be applied to a particular device or design.

This report is divided as follows: description of tests, figures, tables, and appendix.

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1.0 INTRODUCTION

DCA Reliability Laboratory, under contract NAS8-31944 for NASA/Marshall Space Flight Center, has compiled data for the purpose of evaluating the effect of power/temperature step stress when applied to a variety of semiconductor devices. This report covers the PNP transistor JANTX2N2605 manufactured by Raytheon and National Semiconductor.

A total of 48 samples from each manufacturer was submitted to the process outlined in Table 1. In addition, two control sample units were maintained for verification of the electrical parametric testing.

2.0 TEST REQUIREMENTS

2.1 Electrical

All test samples were subjected to the electrical tests outlined in Table 2 at each measurement point after completing the prior power/temperature step stress point. These tests were performed using the Fairchild Model 600 high-speed computer-controlled tester. Additional bench testing was also required on the devices.

2.2 Stress Circuit

The test circuit shown in Figure 1 was used to power all of the test devices during the power/temperature stress conditions. The current was set by I_E and the V_{CE} was varied in order to comply with the specified power rating for this device. At least one of the devices was subjected to maximum rated power (MRP). All remaining devices were subjected to no less than 90% of MRP. See Figure 1 for load resistance values and voltages.

2.3 Group I - Power Stress

Thirty-two units, 16 from each manufacgurer, were submitted

to the power stress process. The transistors were stressed in 500-hour steps at 50, 100, 125, 150, and 175 percent of maximum rated power for a total of 2500 hours or until 50% or more of the devices in a sample lot failed.* Electrical measurements were performed on all specified electrical parameters after each power step. See Table 1.

2.4 Group II - Temperature Stress I

Thirty-two units, 16 from each manufacturer, were submitted to the Temperature Stress I Process. Group II was subjected to 1600 hours of stress at maximum rated power in increments of 160 hours. The temperature was increased in steps of +25°C, commencing at +75°C and terminating at +300°C or until 50% or more of the devices failed.* Electrical measurements were performed on all specified electrical parameters after each temperature step. See Table 1.

2.5 Group III - Temperature Stress II

Thirty-two units, 16 from each manufacturer, were submitted to the Temperature STress II Process. Group III was subjected to 112 hours of stress at maximum rated power in increments of 16 hours. The temperature was increased in steps of +25°C, commencing at +150°C and terminating at +300°C or until 50% or more of the devices in a sample lot failed.* Electrical measurements were performed on all specified electrical parameters after each temperature step. See Table 1.

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*Conditions for failure:

A) Open or short

B) Leakage exceeds the MIL limit by 100 times

C) Other parameters exceed MIL limits by 50% or more.

3.0 DISCUSSION OF TEST RESULTS

3.1 Group I - Power Stress

3.1.1 Raytheon. The Raytheon sample lot completed the entire 2500-hour Group I testing with two catastrophic failures. The first failure occurred 10 hours into the 175% MRP step. Serial number 7099 failed the minimum h_{FE} limit. The last failure occurred 150 hours into the 175% MRP step. Serial number 7103 failed the maximum I_{CBO} limit. Typical characteristics of this sample lot's performance were:

1) The mean value for I_{CBO} changed 157.6pA from an initial mean of 373.7pA to a final mean of 531.3pA.

2) The mean value for $V_{CE(SAT)}$ changed 11.32mV from an initial mean of 98.38mV to a final mean of 109.7mV.

3) The mean value for h_{FE} changed 7.2 from an initial mean of 208.8 to a final mean of 201.6.

The control units for this sample lot remained constant throughout the entire Group I testing.

3.1.2 National Semiconductor. The National Semiconductor sample lot completed the entire 2500-hour Group I testing with two catastrophic failures. The first failure occurred 10 hours into the 150% MRP step. Serial number 7038 failed the maximum I_{CBO} limit. The last failure occurred 500 hours into the 175% MRP step. Typical characteristics of this sample lot's performance were:

1) The mean value for I_{CBO} changed 1.88nA from an initial mean of 295.6pA to a final mean of 2.18nA.

2) The mean value for $V_{CE(SAT)}$ changed 620.14mV from an initial mean of 94.06mV to a final mean of 714.20mV.

3) The mean value for h_{FE} changed 21.9 from an initial mean of 184.0 to a final mean of 162.1.

The control units for this sample lot remained constant throughout the entire Group I testing.

3.1.3 Statistical Summary - Group I

Table 4 outlines the results of Group I - Power Stress Process for all of the specified electrical parameters and all measurement points for both Raytheon and National Semiconductor.

3.2 Group II - Temperature Stress I

3.2.1 Raytheon. The Raytheon sample lot completed a total of 1120 hours of Group II testing before the lot was stopped because 50% of the devices failed. The first failure occurred 160 hours into the +100°C-temperature step. Serial number 7111 failed the maximum h_{FE} limit. The next two failures occurred 160 hours into the +200°C-temperature step. Serial number 7109 failed the minimum h_{FE} limit, and serial number 7117 failed the maximum I_{CBO} limit. The last five failures occurred 160 hours into the +225°C-temperature step. Serial numbers 7107 and 7108 failed the minimum h_{FE} limit. Serial numbaers 7112, 7114, and 7120 failed the maximum I_{CBO} limit. Typical characteristics of this sample lot's performance were:

1) The mean value for I_{CBO} changed 200.2nA from an initial mean of 310.6pA to a final mean of 200.5nA.

2) The mean value for $V_{CE(SAT)}$ changed 4.09mV from an initial mean of 93.31mV to a final mean of 97.40mV.

3) The mean value for h_{FE} changed 85.4 from an initial mean of 217.8 to a final mean of 132.4.

The control units for this sample lot remained constant throughout the entire Group II testing.

3.2.2 National Semiconductor. The National Semiconductor lot

completed 1120 hours of Group II testing before the lot was stopped because more than 50% of the devices failed. The first six failures occurred 160 hours into the +200°C-temperature step. Serial number 7071 failed the minimum h_{FE} limit. Serial numbers 7046, 7049, 7052, 7074, and 7075 failed the maximum I_{CBO} limit. The last four failures occurred 160 hours into the +225°C-temperature step. Serial number 7047 and 7072 failed the maximum I_{CBO} limit. Serial number 7073 failed the maximum $V_{CE(SAT)}$ limit. Serial number 7077 failed the minimum h_{FE} limit. Typical characteristics of this sample lot's performance were:

1) The mean value for I_{CBO} changed 114.2nA from an initial mean of 304.4pA to a final mean of 114.5nA.

2) The mean value for $V_{CE(SAT)}$ changed 2.01V from an initial mean of 90.81mV to a final mean of 2.10V.

3) The mean value for h_{FE} changed 69.1 from an initial mean of 177.0 to a final mean of 107.90.

The control units for this sample lot remained constant throughout the entire Group II testing.

3.2.3 Statistical Summary - Group II

Table 5 outlines the results of Group II - Temperature Stress I testing for all of the specified electrical parameters and all of the measurement points pertaining to both Raytheon and National Semiconductor.

3.3 Group III - Temperature Stress II

3.3.1 Raytheon. The Raytheon sample lot completed 96 hours of Group III testing before the lot was stopped because more than 50% of the devices failed. The 13 catastrophic failures occurred 16 hours into the +275°C-temperature step. Serial numbers 7123, 7129, 7136, 7137, 7138, and 7139 failed the maximum I_{CBO} limit. Serial numbers 7125,

7126, 7127, 7130, 7131, 7134, and 7135 failed the maximum $V_{CE(SAT)}$ limit. Typical characteristics of this sample lot's performance were:

1) The mean value for I_{CBO} changed 865.5nA from an initial mean of 352.9pA to a final mean of 865.9nA.

2) The mean value for $V_{CE(SAT)}$ changed 3.77V from an initial mean of 97.82mV to a final mean of 3.87V.

3) The mean value for h_{FE} changed 50.4 from an initial mean of 208.9 to a final mean of 158.5.

The control units for this sample lot remained constant throughout the entire Group III testing.

3.3.2 National Semiconductor. The National Semiconductor sample lot completed a total of 96 hours of Group III testing before the lot was stopped because more than 50% of the devices failed. The first failure occurred 16 hours into the +150°C-temperature step. Serial number 7084 failed the minimum h_{FE} limit. The next nine failures occurred 16 hours into the +275°C-temperature step. Serial number 7053, 7058, and 7082 failed the maximum I_{CBO} limit. Serial numbers 7059, 7083, and 7085 failed the maximum $V_{CE(SAT)}$ limit. Serial numbaers 7062, 7079, and 7081 failed the minimum h_{FE} limit. Typical characteristics of this sample lot's performance were:

1) The mean value for I_{CBO} changed 285.3nA from an initial mean of 336.7pA to a final mean of 285.6nA.

2) The mean value for $V_{CE(SAT)}$ changed 2.15V from an initial mean of 90.60mV to a final mean of 2.24V.

3) The mean value for h_{FE} changed 4.2 from an initial mean of 188.4 to a final mean 184.2.

The control units for this sample lot remained constant throughout the entire Group III testing.

3.3.3 Statistical Summary - Group III

Table 6 outlines the results for Group III - Temperature Stress II testing for each of the specified electrical parameters and all measurement points for both Taytheon and National Semiconductor.

4.0 FINAL DATA SUMMARY

Table 7 statistically summarizes the change in the mean value from the zero-hour data to the final data. The graphs of Figures 2 and 4 plot the cumulative percent failures versus the temperature stress level for Group II - Temperature Stress I, and Group III - Temperature Stress II. The graphs of Figures 3 and 5 plot the time step for Group II (160 hours) and Group III (16 hours) versus the temperatures T_1 and T_2 calculated from Figures 2 and 4. Tables 8 and 9 summarize the failures encountered for all three stress groups. The failures are separated into catagories: catastrophic failures in Table 8 and parametric failures in Table 9. The data from Table 8 was used as a source for the graphs in Figures 2 and 4. Figures 2 and 4 were used as a source for the graphs in 3 and 5 respectively. Junction temperature is plotted on an inverse hyperbolic scale.

5.0 CONCLUSIONS

Groups II and III testing proved to be the most detrimental of the three groups. Samples from both manufacturers exhibited several microamperes of hysteresis in the BV_{CEO} curve trace, but not in the other configuration. The pattern suggests the presence of contamination. The flow of metal from the gold leads and the intermetallics is one source of such contaminants.

The hysteresis currents in the base can inject base current which is not part of the known base drive. From this the h_{FE} reads high.

At the same time the contaminant may reduce emitter efficiency by reducing the lifetime of holes in the base. This tends to lower the h_{FE}.

So the migration of contaminants during burn-in can have two opposite effects on the h_{FE} reading, and the net result depends upon which effect predominates in the individual sample at the moment of failure. When carried to extremes gold migration in the base region will develop surface and junction leakage problems, and collector-emitter shorts.

Possibly these failures could have been delayed to higher stress levels if aluminum wires were used in place of gold, by removing the fast-migrating gold from the surface of the die.

A plot showing cumulative failure distribution for Groups II and III was drawn for the Raytheon and National Semiconductor sample lots (Figures 2 and 3 and 4 and 5 respectively). Figures 2 and 3 display the data for Raytheon used to calculate an activation energy of 2.37eV. Figures 4 and 5 display the data for National Semiconductor used to calculate an activation energy of 1.84eV.

A broken circle around a marked point, on the graph, indicates a freak failure not calculated as part of the regression line. A solid circle around a marked point indicates an isolated main failure point. The regression line was calculated using the least squares method.

Because of visual defects caused by the extreme heat of the stress tests, serial numbers 7130, 7133 and 7135 were not calculated as part of the regression line.

The activation energy was calculated from the formula:

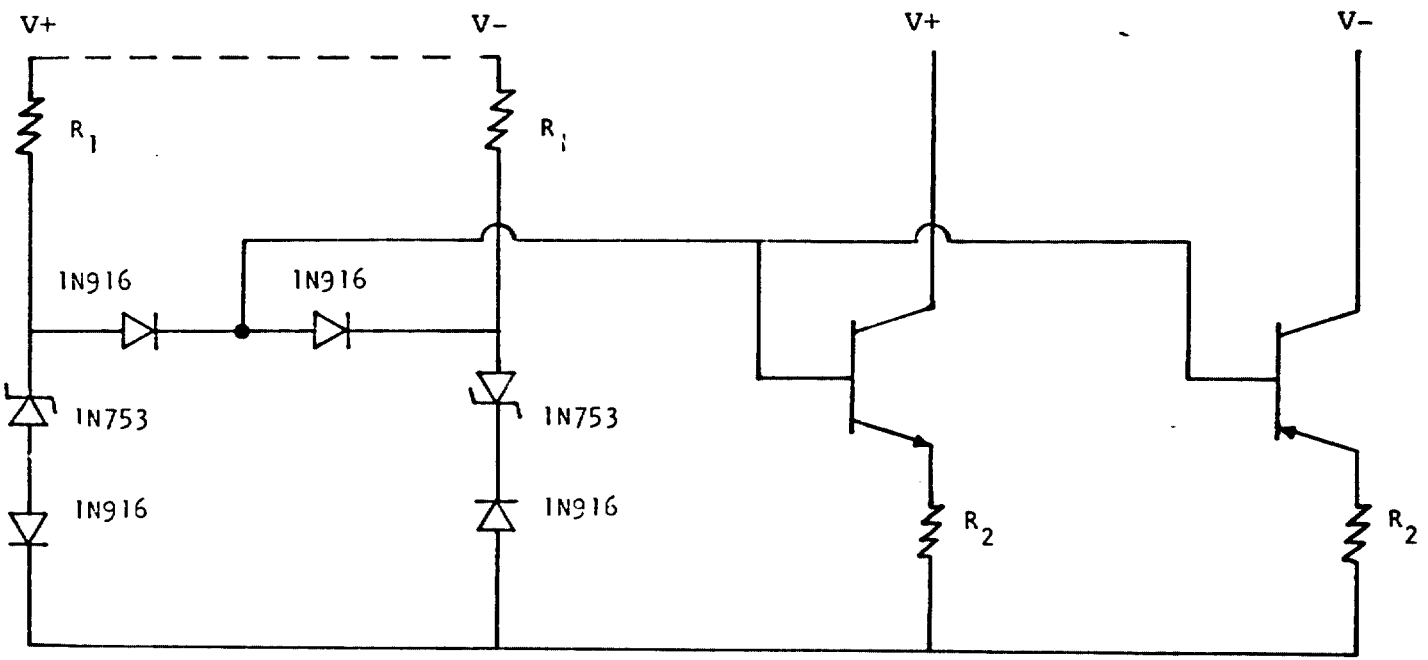
$$E = \left[\ell n \left(\frac{t_1}{t_2} \right) \right] \left[\frac{8.63 \times 10^{-5} \text{ eV/}^{\circ}\text{K}}{\left(\frac{1}{T_1 + 273} \right) - \left(\frac{1}{T_2 + 273} \right)} \right] \text{eV}$$

Where: t_1 = step of Group II - Temp Stress I = 160 hrs.

t_2 = step of Group III - Temp Stress II = 16 hrs.

T_1 = temperature in $^{\circ}$C of 16% failure for Group II.

T_2 = temperature in $^{\circ}$C of 16% failure for Group III.



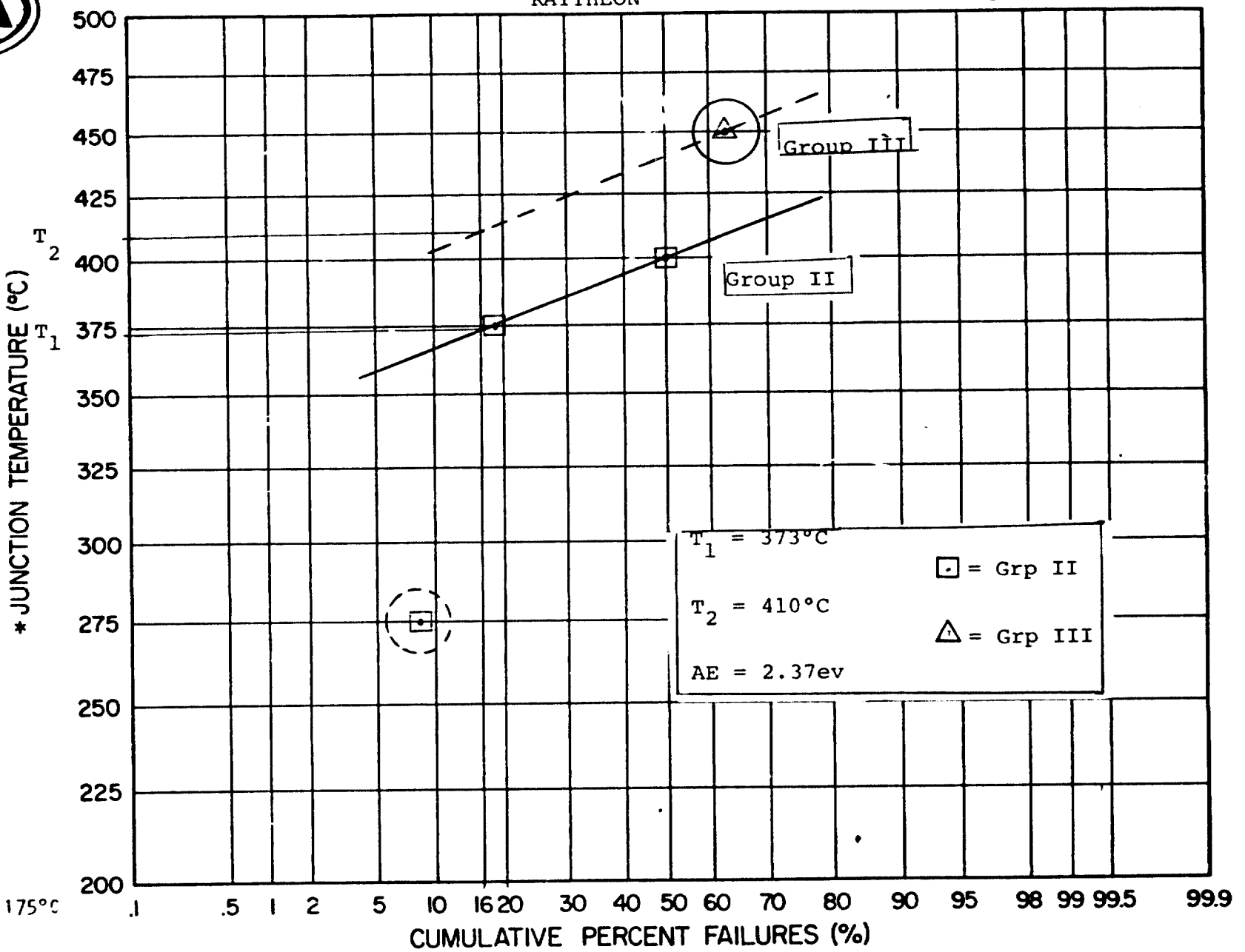
NOTES: R_1 = 800±5%, 2W. R_2 = 475Ω±1%, ½W

Use V+ for NPN Transistors. Use V- for PNP Transistors. See Table 3 for V values.

FIGURE 1

Power/Temperature Stress Circuit
JANTX2N2605

JANTX2N2605



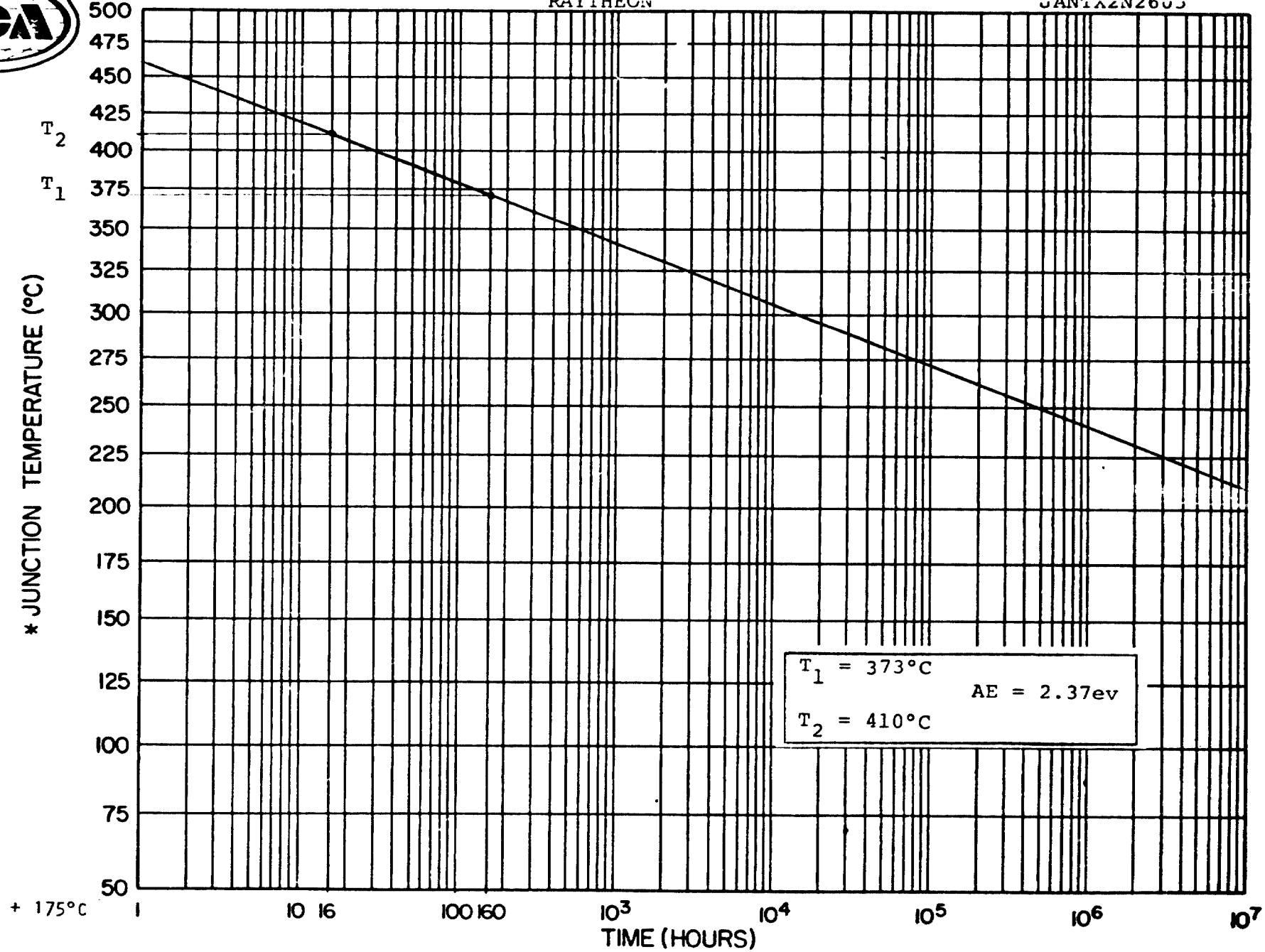
*NOTE

$T_J \approx T_A + 175°C$

FIGURE 2

Cumulative Percent Failures Versus Junction Temperature, Raytheon

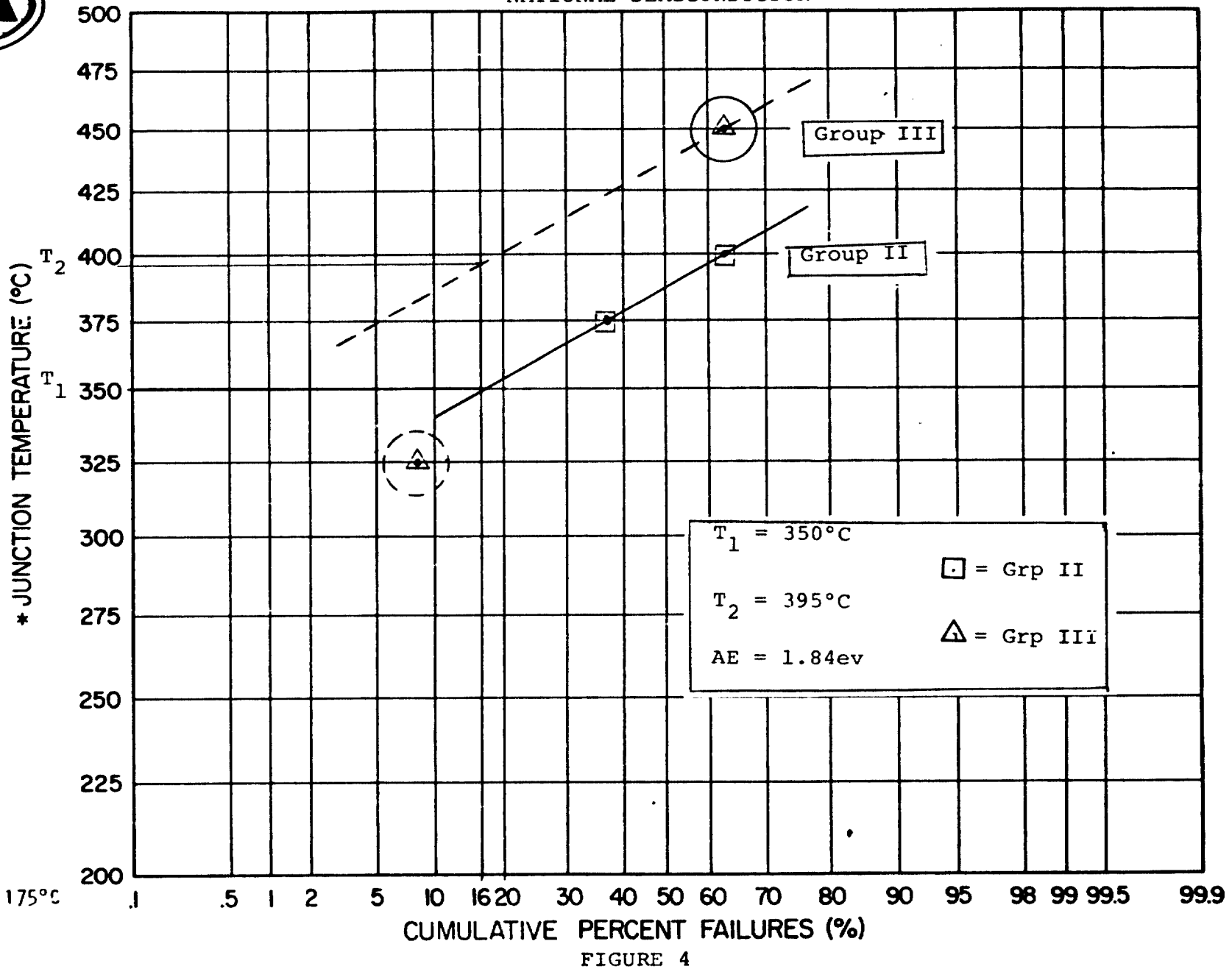
JANTX2N2605



*NOTE

$T_J \approx T_A + 175°C$

FIGURE 3
Time Steps Versus Junction Temperature, Raytheon

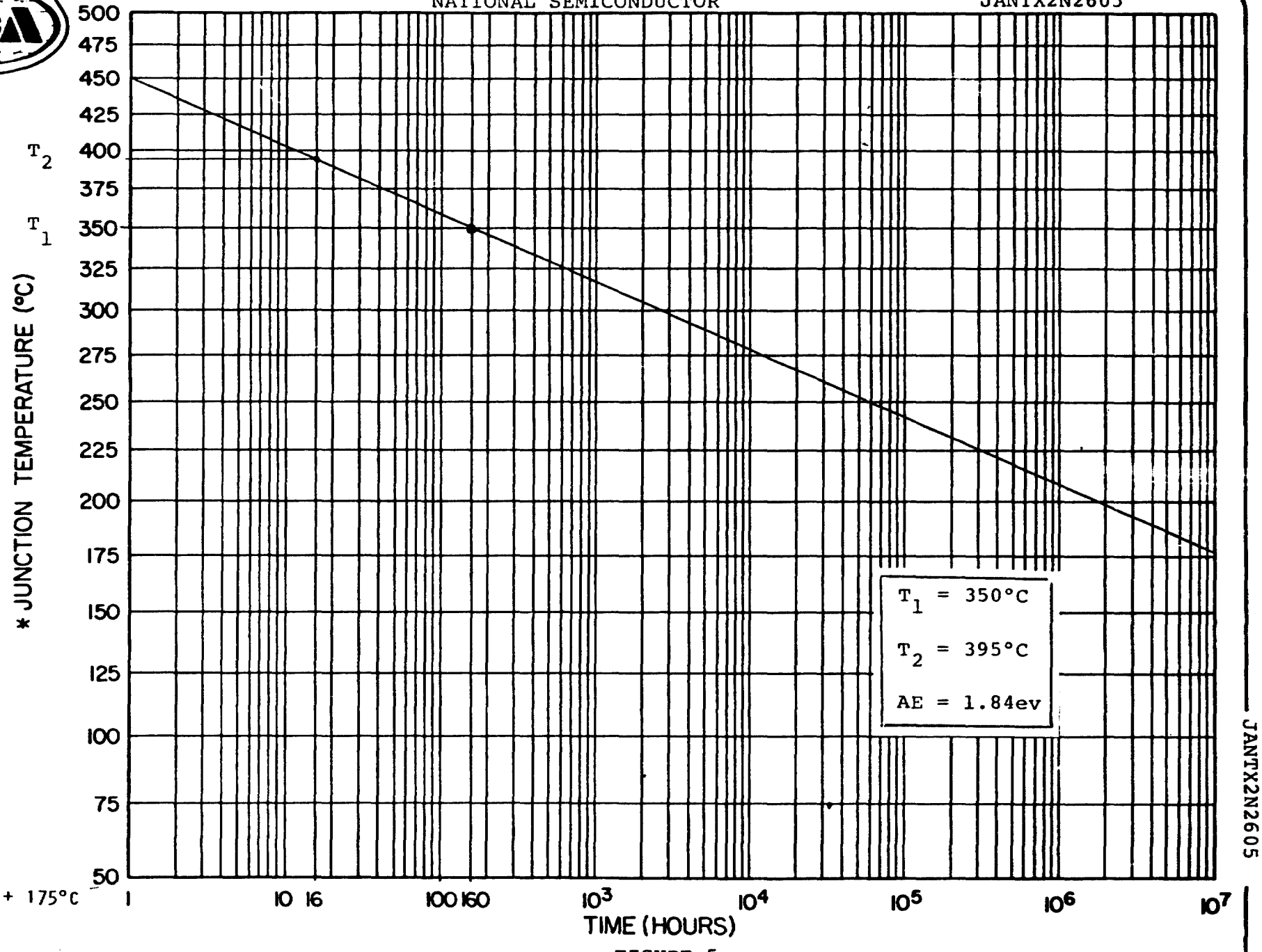


*NOTE

$T_J \approx T_A + 175°C$

FIGURE 4

Cumulative Percent Failures Versus Junction Temperature, National Semiconductor

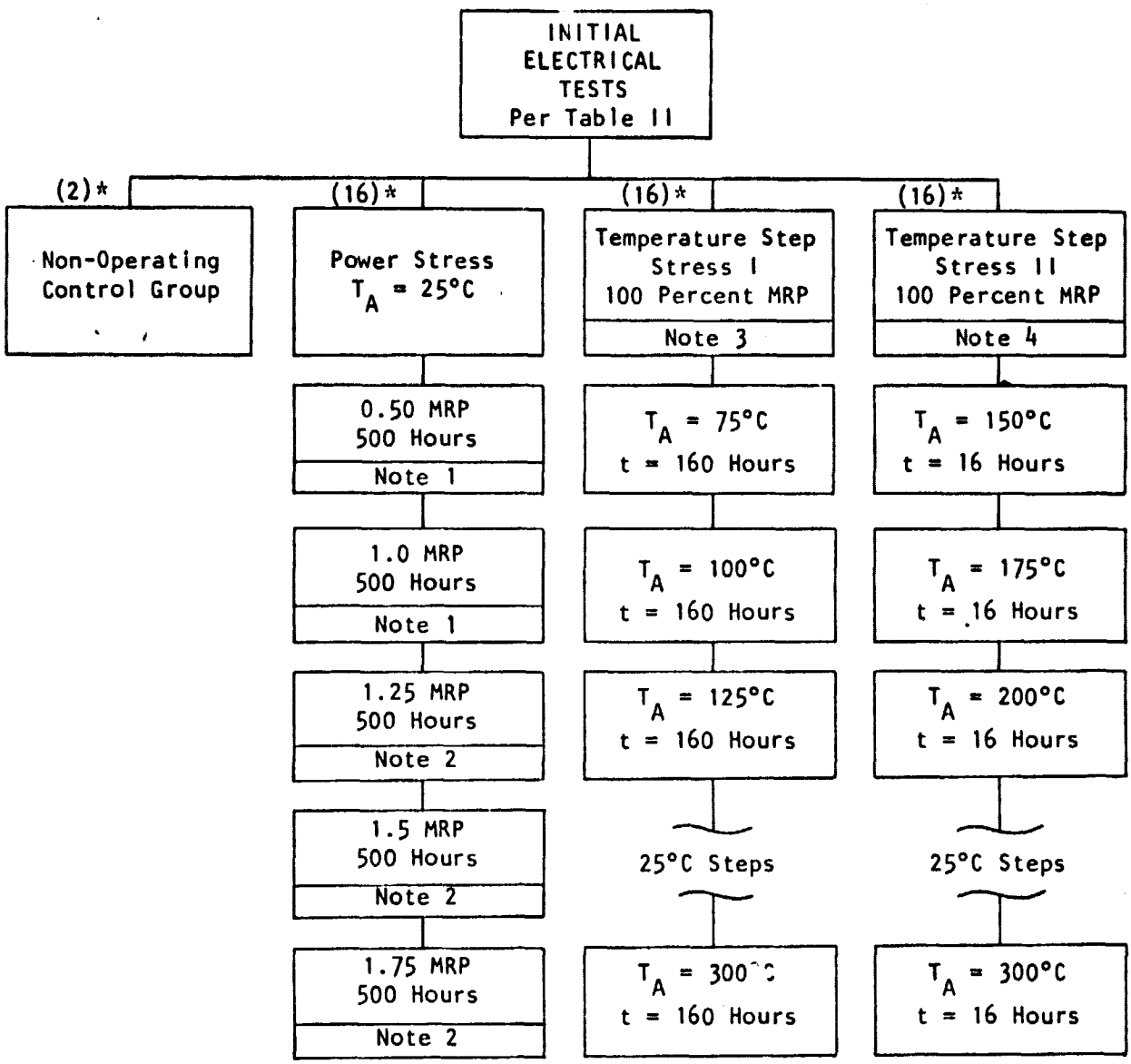


*NOTE

$T_J \approx T_A + 175°C$

FIGURE 5
Time Steps Versus Junction Temperature, National Semiconductor

TABLE I
TEST FLOW DIAGRAM



*Quantity per manufacturer (Raytheon & National Semiconductor)

NOTES:

1) Electrical measurements per Table 2 were made at 50, 150, 250 and 500 hours.
2) Electrical measurements per Table 2 were made at 10, 25, 50, 150, 250 and 500 hours.
3) Electrical measurements per Table 2 were made at the end of each 160 hours.
4) Electrical measurements per Table 2 were made at the end of each 16 hours.

TABLE 2
PARAMETERS AND TEST CONDITIONS

PARAMETER	CONDITIONS	SPEC. LIMIT		CAT. LIMIT		UNITS
		MIN	MAX	MIN	MAX	
I_{CBO}	@V_{CB} = -50V		-10		-1000	nA
$V_{CE(SAT)}$	@I_C = -10mA & I_V = -.5mA		-.5		-.75	V
h_{FE}	@V_{CE} = -5V & I_C = -10μA	100	300	50	450	-

NOTES:
IN ADDITION, ANY OPEN OR SHORT SHALL BE CONSIDERED CATASTROPHIC.

TABLE 3
POWER STRESS BURN-IN CONDITIONS

I_E = 15.0mA	
V_{CE}=	Percent P_D
12.5V	50
25.0V	100
31.2V	125
37.5V	150
43.7V	175

TABLE 4
GROUP I — POWER STRESS DATA SUMMARY

PARAMETER	I_{CBO} = -10nA(max)		$V_{CE(SAT)}$ = -.5V(max)		h_{FE} = 100(min) 300(max)			
CONDITIONS AND LIMIT	@V_{CB} = -50V		@I_C = -10mA, I_B = -.5mA		@V_{CE} = -5V, I_C = -10μA			
IDENTIFICATION	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL		
INITIAL DATA								
MIN VALUE	230.0pA	60.00pA	83.00mV	80.00mV	89.30	147.0		
MAX VALUE	1430.opA	350.00pA	113.00mV	113.00mV	289.00	231.0		
MEAN	373.7pA	295.60pA	98.38mV	94.06mV	208.80	184.0		
STD DEV	275.0pA	62.95pA	9.41mV	9.90mV	52.46	27.4		
INTERIM DATA								
POWER 50 TO 125% Δ MEAN VALUE								
50% POWER								
50 HRS	57.5pA	64.4pA	1.56mV	0.07mV	9.8	3.6		
150 HRS	82.5pA	80.0pA	0.18mV	0.13mV	12.0	3.1		
250 HRS	36.3pA	53.1pA	0.68mV	0.38mV	12.9	3.6		
500 HRS	25.0pA	14.4pA	0.07mV	0.07mV	11.4	1.5		
100% POWER								
550 HRS	11.9pA	12.5pA	5.62mV	-0.31mV	13.7	2.6		
650 HRS	7.5pA	14.4pA	0.31mV	0.07mV	13.2	1.9		
750 HRS	- 1.8pA	- 2.5pA	-0.63mV	-0.87mV	17.5	0.7		
1000 HRS	99.4pA	- .6pA	7.12mV	-0.68mV	21.0	1.4		
125% POWER								
1010 HRS	376.9pA	20.6pA	6.72mV	-1.50mV	21.0	1.4		
1025 HRS	160.7pA	140.0pV	7.04mV	-2.06mV	19.0	1.0		
1050 HRS	- 3.7pA	330.6pA	-1.25mV	-2.81mV	19.8	1.2		
1150 HRS	115.7pA	590.6pA	6.02mV	-4.06mV	21.0	-0.4		
1250 HRS	0.0pA	*1.3μA	9.42mV	-2.50mV	30.0	7.5		
1500 HRS	171.3pA	183.1pA	8.12mV	-1.37mV	31.1	7.3		

(continued on second sheet)

TABLE 4 (Cont'd)
GROUP I – POWER STRESS DATA SUMMARY

(continued from first sheet)

PARAMETER	I_{CBO}= -10nA(max)		$V_{CE(SAT)}$=-.5V(max)		h_{FE}=100(min) 300(max)			
CONDITIONS AND LIMITS	@V_{CB} = -50V		@I_C=-10mA, I_B=-.5mA		@V_{CE}=-5V, I_C=-10µA			
IDENTIFICATION	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL		
INITIAL DATA								
MIN VALUE	230.0pA	60.00pA	83.00mV	80.00mV	89.30	147.0		
MAX VALUE	1430.0pA	350.00pA	113.00mV	113.00mV	289.00	231.0		
MEAN	373.7pA	295.60pA	98.38mV	94.06mV	208.80	184.0		
STD DEV	275.0pA	62.95pA	9.41mV	9.90mV	52.46	27.4		
INTERIM DATA								
POWER 150 TO 175% Δ MEAN VALUE								
150% POWER								
1510 HRS	160.0pA	*43.9mA	3.22mV	-4.81mV	24.6	5.5		
1525 HRS	191.9pA	201.9pA	7.32mV	-2.25mV	23.6	4.6		
1550 HRS	195.7pA	195.6pA	1.82mV	-1.87mV	23.5	5.0		
1650 HRS	198.2pA	213.1pA	7.32mV	-2.12mV	22.1	3.7		
1750 HRS	193.2pA	200.0pA	6.42mV	-2.12mV	21.4	6.1		
2000 HRS	173.2pA	181.3pA	6.72mV	-1.93mV	23.0	5.6		
175% POWER								
2010 HRS	199.4pA	187.5pA	6.82mV	- 1.62 V	18.7	4.5		
2025 HRS	313.6pA	293.3pA	8.32mV	*617.34mV	17.9	6.2		
2050 HRS	*1.2µA	193.1pA	8.92mV	- 2.12mV	37.7	5.9		
2150 HRS	*8.6µA	293.1pA	9.72mV	- 0.62mV	37.5	5.8		
2250 HRS	403.6pA	469.4pA	9.92mV	- 0.56mV	29.4	- 3.7		
2500 HRS	157.6pA	1.88nA	11.32mV	*620.14mV	- 7.2	-21.9		
FINAL DATA								
MIN VALUE	370.0pA	.40nA	86.00mV	81.00mV	130.00	79.0		
MAX VALUE	1340.0pA	27.20nA	179.00mV	9.99V	351.00	222.0		
MEAN	531.3pA	2.18nA	109.70mV	714.20mV	201.60	162.1		
STD DEV	221.1pA	6.46nA	21.19mV	2.40V	70.72	37.4		

* Catastrophic Rejects removed from data.

TABLE 5

GROUP II TEMP STRESS I DATA SUMMARY (160 HOUR INCREMENTS)

PARAMETERS	I_{CBO} = -10nA(max)		$V_{CE(SAT)}$=-.5V(max)		h_{FE}=100(min) 300(max)			
CONDITIONS AND LIMITS	@V_{CB} = -50V		@I_C = -10mA, I_B=-.5mA		@V_{CE}=-5V, I_C=-10μA			
IDENTIFICATION	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL		
INITIAL DATA								
MIN VALUE	60.0pA	250.0pA	79.00mV	78.00mV	129.0	57.4		
MAX VALUE	430.0pA	370.0pA	125.00mV	117.00mV	294.0	265.0		
MEAN	310.6pA	304.4pA	93.31mV	90.81mV	217.8	177.0		
STD DEV	71.1pA	30.8pA	11.53mV	11.27mV	46.4	45.8		
INTERIM DATA (INITIAL TO FINAL)								
Δ MEAN VALUE 160 HOUR INCREMENTS								
TOTAL HRS / TEMP(T_A)								
160 +75°C	182.5pA	188.1pA	0.38mV	0.44mV	0.5	8.9		
320 +100°C	185.0pA	185.6pA	-6.18mV	- 0.50mV	51.0	10.1		
480 +125°C	200.1pA	186.8pA	-1.11mV	- 1.43mV	2.5	7.3		
640 +150°C	174.4pA	180.6pA	-4.56mV	- 2.06mV	-31.9	8.9		
800 +175°C	244.7pA	200.0pA	1.16mV	8.38mV	0.0	0.5		
960 +200°C	*666.2nA	*2144.7nA	2.76mV	*22.19mV	34.2	55.5		
1120 +225°C	*200.2nA	* 144.2nA	4.09mV	- 2.01V	-85.4	-69.1		
1280 +250°C	JOB STOPPED	JOB STOPPED	JOB STOPPED	JOB STOPPED	JOB STOPPED	JOB STOPPED		
1440 +275°C	↓ ↓	↓ ↓	↓ ↓	↓ ↓	↓ ↓	↓ ↓		
1600 +300°C								
FINAL DATA								
FINAL TEMP (T_A)	225°C	225°C	225°C	225°C	225°C	225°C		
MIN VALUE	60.9pA	220.0pA	0.00mV	81.00mV	0.00	0.00		
MAX VALUE	999.0nA	999.0nA	135.00mV	9.99V	272.00	244.00		
MEAN	200.5nA	114.5nA	97.40mV	2.10V	132.40	107.90		
STD DEV	399.3nA	297.8nA	28.84mV	3.95V	75.45	85.28		

*CATASTROPHIC REJECTS REMOVED FROM DATA

JANTX2N2605

TABLE 6

GROUP III TEMP STRESS II DATA SUMMARY (16 HOUR INCREMENTS)

PARAMETERS	I_{CBO} = -10nA(max)		$V_{CE(SAT)}$ = -.5V(max)		h_{FE} = 100(min)300(max)			
CONDITIONS AND LIMITS	@V_{CB} = -50V		@I_C = -10mA, I_B = -.5mA		@V_{CE} = -5V, I_C = -10μA			
IDENTIFICATION	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL		
INITIAL DATA								
MIN VALUE	320.0pA	250.0pA	85.00mV	76.00mV	134.0	140.0		
MAX VALUE	530.0pA	610.0pA	109.00mV	109.00mV	299.0	246.0		
MEAN	352.9pA	336.7pA	97.82mV	90.60mV	208.9	188.4		
STD DEV	60.9pA	77.1pA	7.33mV	9.21mV	41.2	30.3		
INTERIM DATA (INITIAL TO FINAL)								
Δ MEAN VALUE								
16 HOUR INCREMENTS								
TOTAL HRS / TEMP(T_A)								
16 / +150°C	-33.5pA	- 17.4pA	-1.63mV	-1.20mV	- 0.7	- 0.8		
32 / +175°C	-35.4pA	34.0pA	-0.32mV	-1.60mV	1.7	0.7		
48 / +200°C	-45.4pA	- 19.6pA	0.56mV	-1.31mV	- 5.0	- 5.0		
64 / +225°C	-37.9pA	- 31.7pA	-0.57mV	-2.67mV	-10.4	-20.5		
30 / +250°C	10.8pA	- 49.6pA	-1.32mV	-1.89mV	-26.3	-24.2		
96 / +275°C	*865.5nA	*285.3nA	*3.77V	*2.15V	-50.4	- 4.2		
112 / +300°C	JOB STOPPED	JOB STOPPED	JOB STOPPED	JOB STOPPED	JOB STOPPED	JOB STOPPED		
FINAL DATA								
FINAL TEMP (T_A)	+275°C	+275°C	+275°C	+275°C	+275°C	+275°C		
MIN VALUE	310.0pA	70.0pA	94.00mV	79.00mV	142.0	105.0		
MAX VALUE	999.0nA	999.0nA	9.99V	9.99V	175.0	244.0		
MEAN	865.9nA	285.6nA	3.87V	2.24V	158.5	184.2		
STD DEV	339.4nA	451.2nA	3.82V	4.05V	16.5	49.8		

*CATASTROPHIC REJECTS REMOVED FROM DATA

TABLE 7
FINAL DATA SUMMARY

PARAMETER	SPECIFICATIONS LIMIT		UNITS	MEAN INT. DATA	AVERAGE Δ IN MEAN VALUE					
					POWER STRESS		TEMPERATURE STRESS I		TEMPERATURE STRESS II	
	MIN	MAX			RAYTHEON	NATIONAL	RAYTHEON	NATIONAL	RAYTHEON	NATIONAL
I_{CBO}	-	-10.0	nA		+377.05 *	+1688511.8 *	+123.91 *	+322.83 *	+144.23 *	+47.536 *
$V_{CE(SAT)}$	—	-0.5	V		+.00534	+.04623	-.00049	-.28328	+.62770	+.35689
h_{FE}	100.0	300.0	-		+20.215	+2.4154	-4.1571	+3.1571	-15.183	-9.000

* Catastrophic reject(s) removed from data.

TABLE 8 STEP STRESS CATASTROPHIC FAILURE SUMMARY JANTX2N2605

GROUP I POWER STRESS

TEST STEP	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
50% 50 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
100% 50 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
125% 10 hr.	0	-	0	-
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
150% 10 hr.	0	-	1	B
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
175% 10 hr.	1	A	0	-
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	1	B	0	-
100 hr.	0	-	0	-
250 hr.	0	-	1	A

GROUP II 160 HR. TEMP. STEPS

TEST STEP (T_A)	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
75° C	0	-	0	-
100° C	1	C	0	-
125 °C	0	0	0	-
150 °C	0	0	0	-
175 °C	0	0	0	-
200 °C	1 / 1	A / B	1 / 5	A / B
225 °C	2 / 3	A / B	1 / 2 / 1	A / B / D
250 °C	JOB STOPPED		JOB STOPPED	
275 °C	↓	↓	↓	↓
300 °C	↓	↓	↓	↓

GROUP III 16 HR. TEMP. STEPS

TEST STEP (T_A)	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
150°C	0	-	1	A
175°C	0	-	0	-
200°C	0	-	0	-
225°C	0	-	0	-
250°C	0	-	0	-
275°C	6 / 7	B / D	3 / 3	A / B
300°C	JOB STOPPED		JOB STOPPED	

MFR "A" = RAYTHEON

MFR "B" = NATIONAL SEMICONDUCTOR

NOTES:

(A) $h_{FE}<50$

(B) $I_{CBO}>1.0\mu A$

(C) $h_{FE}>450$

(D) $V_{CE(SAT)}>.75V$

TABLE 9 STEP STRESS PARAMETRIC FAILURE SUMMARY JAN TX2N2605

GROUP I POWER STRESS

TEST STEP	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
50% 50 hr.	1	A	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	0	-
100% 50 hr.	0	-	0	-
100 hr.	1	B	0	-
100 hr.	3	B	0	-
250 hr.	0	-	0	-
125% 10 hr.	0	-	0	-
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	1	C
250 hr.	0	-	0	-
150% 10 hr.	1	A	0	-
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	1	B	0	-
175% 10 hr.	0	-	0	-
15 hr.	0	-	0	-
25 hr.	0	-	0	-
100 hr.	0	-	0	-
100 hr.	0	-	0	-
250 hr.	0	-	1	A

GROUP II 160 HR. TEMP. STEPS

TEST STEP (T_A)	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
75° C	0	-	1	A
100° C	0	-	0	-
125 °C	0	-	1	A
150 °C	0	-	0	-
175 °C	0	-	0	-
200 °C	0	-	0	-
225 °C	0	-	1	A
250 °C	JOB STOPPED		JOB STOPPED	
275 °C	↓	↓	↓	↓
300 °C	↓	↓	↓	↓

GROUP III 16 HR. TEMP. STEPS

TEST STEP (T_A)	MFR A		MFR B	
	QTY.	NOTE	QTY.	NOTE
150°C	0	-	0	-
175°C	0	-	0	-
200°C	1	A	0	-
225°C	2	B	1	A
250°C	1	A	0	-
275°C	0	-	0	-
300°C	JOB STOPPED		JOB STOPPED	

MFR "A" = RAYTHEON

MFR "B" = NATIONAL SEMICONDUCTOR

NOTES:

(A) h_{FE} MINIMUM LIMIT FAILURE

(B) h_{FE} MAXIMUM LIMIT FAILURE

(C) I_{CBO} MAXIMUM LIMIT FAILURE

FAILURE ANALYSIS

MSFC STEP-STRESS TEST
FAILURE ANALYSIS
TRANSISTORS

JANTX2N2605

Date 1 June 1978

J/N 2CN242-05 B P/N 2N2605 (PNP) MFR National S/C

FAILURE VERIFICATION: Max = 10nA Limits = 100-300

S/N	BV_{CEO} -volts-	BV_{CEO} -volts-	I_{CBO} -nA- @V_{CB} = -50 V	BV_{EBO} -volts-	h_{FE} @ I_C = -10μA; V_{CE} = -5V	V_{BEO} - volts - @ I_{BEO} = 10 nA	Initial Rej. @ Test Seq. No.:	Initial Rej. for
7050	107 H	156	0.5nA	9.5	120	0.83	01 (25°C)	h_{FE}
7077	100	100	0.2nA	10.2	0.27	0.78	15(225°C)	CAT
7078	92 H	124	0.1nA	10.0	454	0.82	15(225°C)	h_{FE}

INTERNAL VISUAL INSPECTION:

All the National Semiconductor samples exhibit $AuAl_2$ ("purple plague") intermatallic formation where the gold wires contact the emitter and base aluminum metallization. See Figure A-1.

S/N 7078 has edge cracks which are directed toward the center of the die. These cracks are a reliability hazard, but are not the cause of the present failure.

*h_{FE} trace present. Cannot meet stated test conditions. (Leaky)
**h_{FE} trace very leaky.

D = drift H = hysteresis Inv = inversion R = resistive S = soft Uns = unstable

MSFC STEP-STRESS TEST FAILURE ANALYSIS TRANSISTORS

JANTX2N2605

Date 1 June 1978

J/N 2CN242-05 B P/N 2N2605 (PNP) MFR Raytheon S/C

FAILURE VERIFICATION: Max/=10nA Limits = 100-300

S/N	BV_{CEO} - volts -	BV_{CEO} - volts -	I_{CBO} - nA - @V_{CB} = -50V	BV_{EBO} - volts -	h_{FE} @ I_C = -10μA; V_{CE} = -5V	V_{BEO} - volts - @ I_{BEO} = 10nA	Initial Rej. @ Test Seq. No.:	Initial Rej. for
7111	96H	126	0.1nA	8.8	219*	0.79	05 (100°C)	CAT
7112	25 → 62 H	30 → 90 D	50μA	8.7	149*	0.80	15 (225°C)	I_{CBO}
7117	0.74	12 R	--	7.7	150**	0.80	13 (200°C)	h_{FE}
	Beta measured at 0.5 volts V_{CE} because of low V_{CE}.							

INTERNAL VISUAL INSPECTION:

All the Raytheon samples exhibit $AuAl_2$ ("purple plague") intermetallics where the gold wires contact the emitter and base aluminum metallization. See Figure A-2.

*h_{FE} trace present. Cannot meet stated test conditions. (Leaky)
**h_{FE} trace very leaky.

D = drift H = hysteresis Inv = inversion R = resistive S = soft Uns = unstable

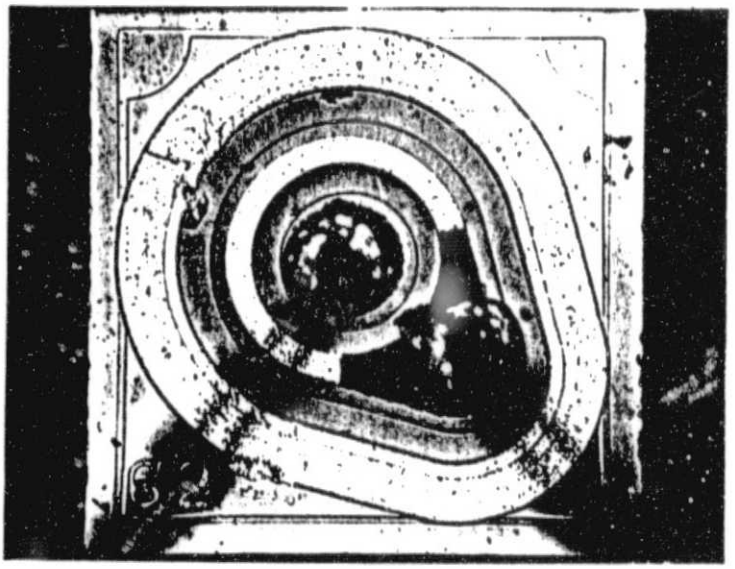


FIGURE A-1

S/N 7078, National Semiconductor, 160X
Overall die view showing "purple plague" formation
on base and emitter metallization.

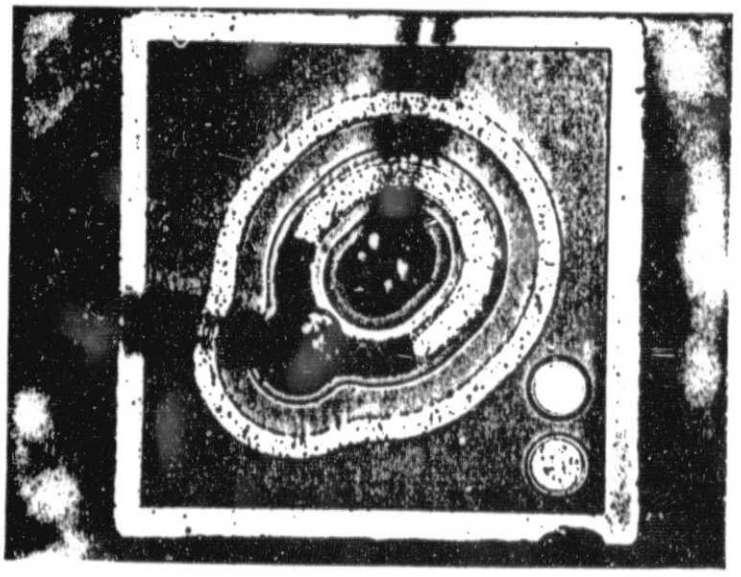


FIGURE A-2

S/N 7117, Raytheon, 160X
Overall die view showing "purple plague" formation
on base and emitter metallization.

CONCLUSIONS:

All six samples in this analysis exhibit several micro-amperes of hysteresis in the BV_{CEO} curve trace, but not in the other configurations. The pattern suggests the presence of contamination in (or on) the base diffusion. The flow of metal from the gold leads and the intermatallics is one source of such contaminations.

The hysteresis currents in the base can inject base current which is not a part of the known base drive. Thus the calculated h_{FE} reads high.

At the same time the contaminants may reduce emitter efficiency by reducing the lifetime of holes in the base. This tends to lower h_{FE}.

Thus the migration of contaminants during the burn-in can have two opposite effects on the h_{FE} reading, depending upon which effect predominates in the individual sample at the moment of failure. When carried to extremes, gold migration in the base region will develop surface and junction leakage problems, and collector-emitter shorts. S/N 7112 is an example of such a surface problem, S/N 7078 is an example of rising h_{FE}, S/N 7077 exhibits falling h_{FE}, and S/N 7117 demonstrates an approaching collector-emitter short.

Possibly these failures could have been postponed to higher stress levels if aluminum wires were used instead of gold to prevent the fast-migrating gold from contaminating the surface of the die.